Bioluminescence Potential in the Transition Zone to Very Shallow Water (VSW)

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LONG-TERM GOALS

The long-term goal is to advance our understanding of the ecology of bioluminescent organisms and the mechanisms governing the temporal and depth-dependent variability of bioluminescence in the coastal ocean. With improvements in technology, finer-scale resolution and concurrent physical, chemical and biological data are available to advance our understanding of the forcing mechanisms governing the temporal and depth-dependent variability of bioluminescence in environments of Naval relevance.

OBJECTIVES

General patterns of bioluminescence potential in surface waters indicate that there is an increased signal in near shore waters. While present regional and coastal models are able to show this coastal enhancement, the model grids are not scaled to the physical dynamics governing the transition zone from the near shore to the shoreline. In addition, few measurements of bioluminescence have been made in this transition region because of limitations in both platforms and sensors. This is despite the stated need in a recent report (National Research Council 2003). The report highlights bioluminescence as an environmental variable that often influences planning and execution of naval missions, and, in general, the need for more understanding of littoral processes. The objective of this project is to better characterize bioluminescence in the transition zone from the near shore to very shallow water (VSW) environments. Measurements of bioluminescence and other parameters will be made in conjunction with other ONR-sponsored physical oceanographers and near shore modelers to provide a basis for a global understanding of how bioluminescent organisms respond in these turbulent and high sheer environments. Specifically the objectives are to; 1) Focus measurements in the transition zones from the near shore to VSW environments (including the surf zone) in conjunction with other physical measurements. 2) Relate cross-shore and along-shore measurements to the shoreline types and shoreline morphologies, including entrances to ports and harbors over a range of relevant time scales (i.e. tidal). 3) Elucidate differential responses between autotrophic and heterotrophic organisms to turbulent and high sheer environments.

APPROACH

The approach to address the primary objectives above was to take advantage of two ongoing studies in California in collaboration with two ONR-funded physical oceanographers (R. Guza, SIO and E.

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Thornton, NPS), with specialties in the surf zone and near shore transition environments. One was in Huntington Beach, CA, and the other in Monterey Bay. The primary focus of these studies was to examine the effects of offshore wave energy (where the depth is greater than 1/20th of the wavelength of the wave) as it propagates inshore and influences, near shore waves, shear/turbulence fields and along- and cross-shore flows. Temporal and spatial measurements of bioluminescence were made as part of this studies in a continuing effort to define the distribution of near shore bioluminescence (see below). In addition to these efforts, a continued effort to obtain a long time series of bioluminescence is ongoing as well as involvement in a number of ancillary ONR projects to address the long-term goals stated above.

WORK COMPLETED

In order to address questions related to bioluminescence in the surf zone, the REMUS-100 vehicle the REMUS AUV platform equipped with a bioluminescence bathyphotometer (Blackwell *et al.*, 2002; Moline *et al.*, 2005) was deployed repeatedly in two location; Huntington Beach, CA and Monterey Bay, CA. In Huntington Beach, CA, 6 bioluminescence missions were conducted from September 20th to October 7th, 2006. The mission grid was set up to examine the transition zone from the surf zone offshore and was 1.5 km by 0.5 km oriented alongshore. An initial survey of the location of breaking waves alongshore was made and used in setting up the grid. The grid entered the surf zone to the greatest extent in the northern corner. There was a gap in the grid around the in situ surf zone instrumentation. An onshore-offshore transect was also part of each mission to examine the vertical distribution of bioluminescence and currents in this region. In Monterey Bay, three deployments were made from May 19th through the 21st, 2007 off of Sand City, CA. The deployment strategy was much like the one set up for Huntington Beach (see above), however the alongshore extent was reduced. The water depths within the programmed grid ranged from 11 to 4 m. During the deviation the vehicle was in 2 m water depth. The wave heights measured during the experiment were consistent at 2 m and normal to the angle of the beach (data not shown). The vehicle operated at 1 m during the 19th of May and was reprogrammed to 2 m on the two subsequent missions.

Complementary Studies
Temporal measurements of bioluminescence have been ongoing in San Luis Obispo Bay. The vertical record from the automated profiler is now over 27 months long. Time series analysis is now being applied to this data set to elucidate the major forcing mechanisms leading to bioluminescent events.

We were able to integrate into the Layered Organization in the Coastal Ocean (LOCO) ONR-DRI at the invitation of the PIs. For 8 successive nights, bioluminescence measurements were made with the AUV around the central study area in support of previous sampling objectives. Additionally, 3 additional sampling deployments were conducted in Monterey Bay in conjunction with K. Benoit-Bird acoustic measurements. Efforts to analyze these data and integrate within the larger study are ongoing (see below). As an aside, the REMUS AUVs in the Moline lab have now surpassed 3,300 km of underwater measurements, the majority related to the bioluminescence work and DOD related projects.

RESULTS

HUNTINGTON BEACH 2006
As this was the first attempt at operating in and around the surf zone, it was important to establish the operational performance of the vehicle in this environment. Long Baseline (LBL) acoustic navigation was used for these missions using 4 transponders, three alongshore and one offshore in a “T” pattern to

ensure coverage both within the grid and along the transect. The transponders remained on moorings throughout the experiment to improve logistics. There was good LBL coverage in the grid, with mean Inband SNR above 50 (dB), however, as the vehicle entered the surf zone, acoustic coverage occasionally dropped out and was dependant on sea state and wave conditions. The area of no coverage under these circumstances was restricted to the inshore 30 m of each leg. In this region, dead reckoning by compass was the default and was used for each of the inshore turns. The bathymetery in the grid ranged from 3.5 to 9 m with the offshore transect extending to 25 m. The 6 hour missions were monitored from the zodiac using a acoustic ranger as well as the iridium, with the vehicle calling in at the offshore extent of the transect each time. The vehicle completed all 6 missions totaling 244 km underwater without any deviation from the planned route and with no data gaps.

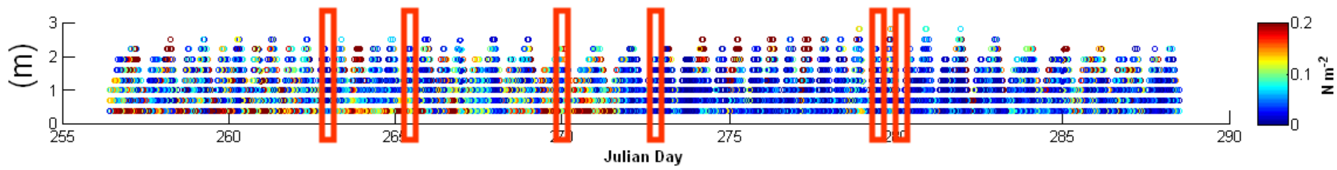

Figure 1. AUV Sampling From Hutington Beach, CA in 2006 [(upper panel) Depth distribution of estimated shear stress measured during the Huntington Beach experiment during September and October, 2006. Open rectangles depict the timing of AUV missions.]

Physical data indicated that there was generally a declining wave height over the study period. For the periods of UUV deployment, the wave period was consistent around 10 s. Deployments were also conducted at different times during the tidal cycle as they required deployment between 22:00 and 04:00 for the bioluminescence measurement (Figure 1; Moline *et al.*, 2000). The wave angle was consistently from the south throughout the experiment with variability of +/- 10°. The angle of the waves shifted by about 10° halfway through the experiment and was found to directly effect the alongshore currents, with higher currents (20 cm/s) to the northwest during the first half of the experiment (data not shown). Cross shore exchange offshore varied with wave height increasing to 10 cm/s during the initial peak wave heights on September 20th, 2006. In this study location there was no measured onshore flow.

MONTEREY BAY 2007

Three missions were conducted in Monterey Bay with two being concurrent with physical shear measurements as part of the RIPEX experiment; May 19th and 20th, 2007. The area measured was a 500m alongshore versus 300 m cross-shore box. Bathymetry and drifter data from collaborators indicated that there were 5 rip channels in the sampling area. The AUV track was designed to sample just offshore to these channels, without being entrained in the surf zone. The vehicle was able to sample in ~2 m water depth with 3 m surf during the experiment to examine the structure of bioluminescence in the surf zone. Decreases in bioluminescence were evident inshore despite continuous high bioluminescent phytoplankton load (chlorophyll a; Figure 2). These measurements indicated a clear pattern of decreased bioluminescence within the surf zone transition. ADCP measurements taken in the center of the box were used to generate a vertical profile of shear for the 19th and 20th of May, 2007, which showed high shear forces increasing toward the surface (Figure 3). As the vehicle was flying within these moderate shear forces (0.07-0.08 N m^{-2}), we were able to quantify the effects on bioluminescence. Bioluminescence patterns for both days were similar, showing highly significant decreases ($p<0.001$) in these high shear environments (Figure 3).

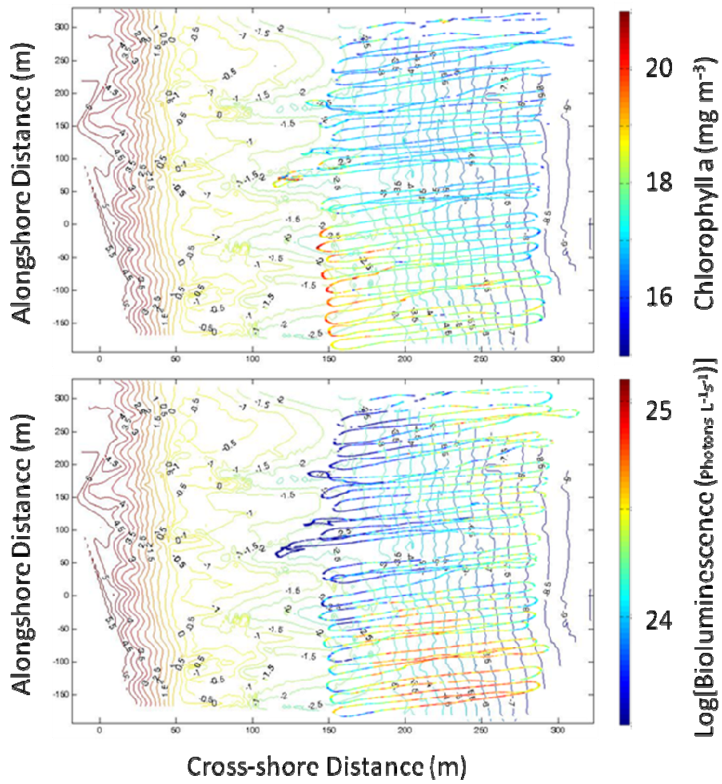

Figure 2. AUV Sampling From Monterey Bay, CA in 2007 [(upper panel) Measure of chlorophyll a taken offshore of the rip channels in the RIPEX sampling area with an AUV sampling at 1 m depth. The grid overlays the hyperbathymetry from the area. (lower panel). Similar to the upper panel except for bioluminescence. Note the decreasing intensity inshore despite high chlorophyll a.]

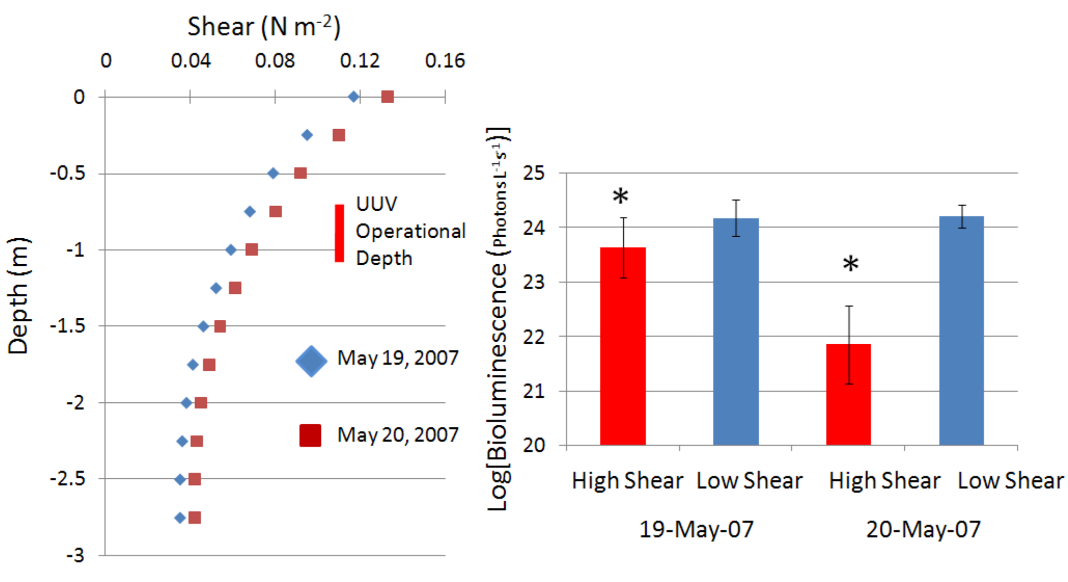

Figure 3. Depth distribution of shear from Monterey Bay in 2007 and effects on bioluminescence. [(left panel) Depth distribution of estimated shear stress and AUV operational depth. (right panel) Decreases in bioluminescence in high shear environments for both sampling days.]

Taking the Huntington Beach and Monterey Bay experiments together and relating the mean bioluminescence to the shear measured on the inshore edge of the AUV sampling grid, there was a significant relationship found, with the mean bioluminescence decreasing as a function of shear forcing. While this does not take into account the organismal loadings, chlorophyll a biomass indicated that these loads were relatively constant within studies. The fact that the Monterey Bay experiment showed the lowest bioluminescence with the highest chlorophyll biomass suggests that this relationship may not be linear as assumed in Figure 4.

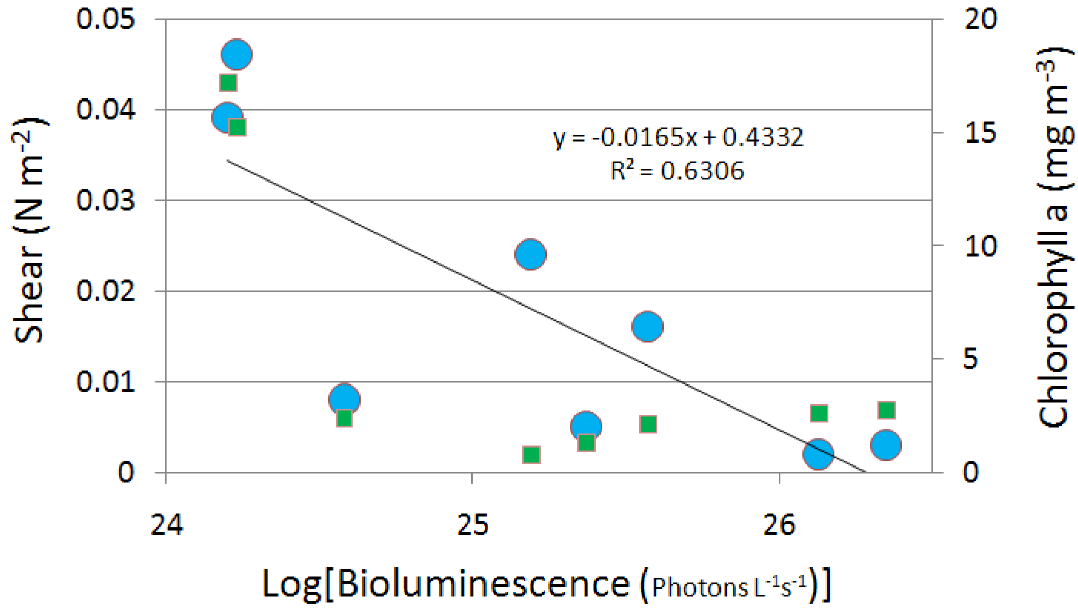

Figure 4. Relationship between shear and bioluminescence from Huntington Beach, CA in 2006 and Monterey bay in 2007. [Data show significant decreasing bioluminescence with increasing shear, with minimal changes to the autotrophic biomass. Note: Monterey bay data are the two highest values of shear.]

TIME SERIES PROFILER

In May, 2005, the automated profiler on the Cal Poly pier in San Luis Obispo Bay began operation and with intermittent breaks, it has been profiling continuously since then. The profiler has been set to measure the vertical structure of bioluminescence potential in conjunction with physical variables every half hour. Elevated levels are consistent with the phytoplankton growth period from May through August. Very high values are associated with late season dinoflagellate blooms occurring during atmospherically quiescent periods with high solar insulation. Over the period of performance, there have been periods without data were due to power interruption to the profiler, cable replacement and an upgrade from a generation-2 sensor to a generation-3 sensor, in collaboration with UCSB. The profiler has been recently upgraded and has the following instrumentation; 3 BP units, a transmissometer, fluorescence, backscatter, CTD and 2 plankton samplers. Time series analysis of the data is ongoing to examine the seasonal growth patterns, periods of local advection events, and separation of autotrophic and heterotrophic plankton communities. The sampler is also being used to collect a time series of samples for the population genetics study of D. Iglesias-Rodriguez with Lingulodinium polyedrum (see Baker et al. 2008).

IMPACT/APPLICATION

Deployments are detecting patterns in the surf transition zone that have not previously been examined. This is also true for the continuing temporal data set. Integration into other existing programs also provides additional opportunities to examine bioluminescence patterns, structuring mechanisms and potential impacts (i.e. organismal/Naval). Here data show that bioluminescence decreases in the surf zone, which may influence nearshore VSW operations and decision-making. In high energy environments, the surf zone and rip channels may be opportunities for safer ingress and egress. Results supported by this study are currently being examined for integration into a Bio-Optical module being developed for the Navy's NCOM model by NRL.

TRANSITIONS

This project adds a high-resolution nighttime bioluminescence capability to an existing network designed to predict the 3-dimensional structure of coastal currents in the surf zone and transition zone. Fine-scale vertical bioluminescent measurements coupled with ancillary physical/biological measurements will improve the ability to predict bioluminescent events in the near shore littoral regions of interest to Naval operations and tactical mission planning. The sensors developed through S&T funds and used in this study are currently in transition by industry (Wetlabs) under an STTR.

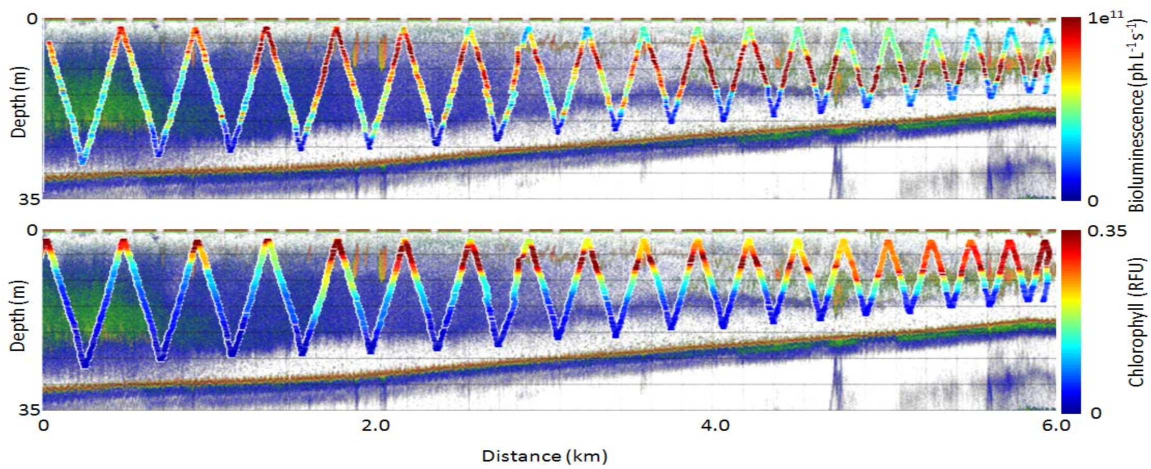

Figure 5. A transect offshore to onshore taken in Monterey Bay on August 4, 2007. Background for both panels is the 120 kHz acoustic scattering taken from the R/V Shana Rae. Overlaid on the panels are the depth distributions of bioluminescence (upper) and chlorophyll (bottom) taken from a REMUS AUV. It is clear from the figures that the scattering layers are related to both parameters, especially evident in waters < 20m. High scattering near shore appear to be from bioluminescent zooplankton that are layered just below the high chlorophyll. Further offshore, the bioluminescence is correlated to the chlorophyll. The strong scattering layer off shore is not bioluminescent, indicating a different population of zooplankton.

RELATED PROJECTS

1 – This project was conducted in conjunction with two near shore State supported programs in California. Surf zone and transition zone data will be analyzed in collaboration with R. Guza and E.

Thornton. 2 – Integration and collaboration with the LOCO scientists will be ongoing to examine layering dynamics in plankton and nekton (Figure 5). 3 – A new STTR project in collaboration with A. Barnard (Wetlabs) and J. Case (UCSB) will help evaluate the new Wetlabs UBAT sensor for bioluminescence measurements. 4- The profiler is also being used to collect a time series of samples for the population genetics study of D. Iglesias-Rodriguez with Lingulodinium polyedrum funded under ONR code 32 OB (see Baker et al., 2008).

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PUBLICATIONS

The following papers were partially or fully supported by this grant award:

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HONORS/AWARDS/PRIZES

Mark A. Moline, named lifetime Fellow of the California Council on Science and Technology (see wwww.ccst.us)